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Municipal Solid Wastes and Their Disposal

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A brief overview is given of the sources, characteristics, and toxic constituents of municipal solid wastes. Several methods are presented for handling, treating, and disposal of solid wastes. Monitoring the landfill site is necessary; there has been a trend to recognize that municipal solid wastes may be hazardous and to provide separate secure handling, treatment, and disposal for their dangerous constituents. Under current state and Federal regulations, permits are being required to assure that proper handling of conventional solid wastes and more hazardous constituents are carefully managed.

Introduction

Municipal solid wastes are generated from residential, commercial, and industrial sources. These solid wastes, exclusive of process type wastes and sludges, are usually mixed together in collection vehicles and are highly compactible. As shown in Table 1, they contain a heterogeneous conglomeration of diverse constituents disposed of by our society (*1*), including newsprint, cardboard, and other miscellaneous paper and wood products; plastics; garden trimmings and brush; food (garbage); textiles; glass; cans; metal; products of building demolition; street sweepings; asphalt; concrete; manures; furniture; dead animals; and so forth.

Municipal solid wastes also often contain all sorts of hazardous and toxic wastes such as pathogens from hospitals or homes; pesticides and herbicides from public parks and private gardens; combustibles such as carbide, gasoline, oil, grease, and ash residues from industrial, commercial, or residential sources; waste explosive materials such as small arms; spray or paint containers; industrial chemicals, both organic and inorganic, and all types of acid and alkali sludges; wastewater treatment residues such as septic tank, and sewage treatment plant sludges; feces from children's disposable diapers; dead animals; and so forth. A breakdown of typical solid waste generation sources reported for the State of Pennsylvania, including an estimate of the quantity of hazardous wastes generated, are listed in Table 2. This table indicates that in Pennsylvania, approximately 5% of the total solid waste quantities are hazardous. Table 3 lists some major industrial plants and their toxic waste sources and constituents.

Hazardous or toxic wastes are defined as materials which are dangerous to human health and the environment. They can be responsible for poisoning, burning, or otherwise injuring or destroying people or other living organisms. Hazardous wastes may act immediately upon being ingested; they can affect the nervous system, may be carcinogenic, or can result in birth defects. Some toxic constituents are not biodegradable and can persist in the water, air, or land, indefinitely. Toxic materials may accumulate in living organisms including the food supply. Pathogenic organisms, oxygen demand, and toxic elements or compounds are commonly present to some degree in any municipal solid waste, and may pose a substantial danger to human, animal, and plant life. As a result of increasing recognition of these problems, there is a trend toward more Federal, state, and local governmental requirements for proper handling and disposal of solid wastes.

Discussion

Originally, municipal solid wastes were commonly disposed of by open dumping, open burning, or incineration. Open dumping can contribute to land litter and water pollution, and the end products of open burning and incineration can contribute to air pollution in the form of particulates, nitrogen oxides, noxious odors, and other constituents. In addition, the burning process can produce solid residues which when ultimately disposed can contribute to water pollution and even help to create some small amounts of methane gas. Municipal incineration with sophisticated energy recovery sys-

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Table 1. Composition of municipal solid wastes.[a]

Category of waste	Oceanside[b]	Los Angeles[c]	Santa Clara[d]	Long Island[e]	National average[f]
	Composition (wet weight), %				
Paper					
Newsprint	7.4	10.7	—	14.0	—
Cardboard	8.2	3.6	—	25.0	—
Miscellaneous paper	23.3	27.0	—	7.0	—
Total	38.9	41.3	55.0	46.0	48.0
Food	12.3	5.3	0.0	12.0	19.0
Glass and ceramics	10.6	7.3	0.0	10.0	8.0
Metals	7.1	6.0	8.0	8.0	9.0
Total vegetation (tree and shrub-prunings, grass & leaves)	12.4	33.1	34.0	10.0	4.0
Textiles	2.2	2.0	0.0	5.0	3.0
Rubber, leather, plastics					
Hard rubber, leather, plastics	4.3	—	—	—	—
Foam rubber and plastic	0.2	—	—	—	—
Total	4.5	2.6	3.0	4.0	4.0
Wood	1.7	1.6	0.0	5.0	2.0
Soil, concrete, rock, ash					
Dirt, sand, ash	0.5			0	3.0
Concrete, rock	0.4	0.8		0	0
Total	0.9	0.8	0.0	0	3.0
Other (2 in. sieve)	9.4				

[a] Data of Stone (*1*).
[b] Composite of four quarterly samples taken during 1971.
[c] Los Angeles, California (wet weight) as received 1/14/71 (88 loads).
[d] Santa Clara, California (*2*).
[e] Long Island, New York (suburban, similar to Oceanside) (*3*).
[f] Data of Hickman (*4*).

Table 2. Sold waste generation in Pennsylvania.[a]

Residuals generated yearly	Million dry metric tons (Tg), (estimated)
Mining and mineral wastes	33.5
Industrial wastes	18.2
Agricultural wastes	24.5
Municipal water and wastewater treatment wastes	0.6
Demolition wastes	1.8
Private, municipal, and commercial refuse	9.1
Total waste generated	87.7
Estimates of hazardous waste generation	3.8-4.96

[a] Data of Merritt and Galida (*5*).

tems were popular in large European and American cities at the turn of the century, but became extinct due to high operating costs. Similarly, in former years, garbage was reclaimed for hog feed; animal wastes were rendered for fats to manufacture soap and other products. These practices have become less popular because of public health requirements to sterilize garbage, and because of the economies of mixed refuse collection. However, the recovery of paper, metals, and other solid wastes continues to be practiced by scrap dealers whenever economically feasible.

In recent years, municipal solid waste incineration has become less popular because of greatly increased air pollution control requirements. Sanitary landfills have become predominant as methods for disposal of municipal solid waste. The sanitary landfill was first nationally applied in Great Britain during World War II as a low cost way of controlling litter and other undesirable open-dumping conditions. Sanitary landfills are normally defined as solid waste sites receiving a daily 6-in. (15 cm) fresh, clean soil cover over compacted refuse generally placed in 5- to 20-ft (1.5- to 6-m) depth cells. The soil cover minimizes flies and rodents by restricting their access to or escape from the organics present in the refuse. The soil cover also helps to bury litter and serves as a road base for the disposal vehicles which will discharge additional waste in the next lift. The earth cover also restricts air movement and prevents fires. A final soil cover, 2 ft deep or more, is placed on the top lift of a landfill to control infiltrating water, grow vegetation, and enable the use of the completed site for other purposes.

The design of sanitary landfills involves multiple professional disciplines and requires a specialized

Table 3. Industrial waste types.[a]

Code No.	Standard industrial classification	Waste type	Composition
20	Food and kindred products		
	Canning	Trimming wastes	Organics
	Meat	Sludges	Organics
	Grain mills	Residues	Acids
22	Textile products		
	Wool, synthetics, cotton	Sludges	Acids, alkalis, metal salts, phenols, oxidizers, dyes, flammable solvents
26	Paper and allied products	Preparation sludges, pulping, sludges waste liquor, fly ash	Sulfates, organics, soaps, sulfites, mercaptans
28	Chemicals and allied plastics,		
	Synthetics	Sludges	Zinc, salts, brines, phenols, acids
	Soaps, detergents	Sludges	Surfactants, polyphosphates, aluminum, copper, and chrome oxides
	Paints, varnishes	Sludges	Metal salts, other toxics
	Chemicals, fertilizers	Sludges	Sulfuric, phosphoric acids, organic phosphorus, copper sulfate, mercury arsenates, spent acids
29	Petroleum refining	Sludges, filter cakes, fly ash	Spent acids, spent caustics, hydrocarbons, metallic salts, cyclic intermediates
31	Leather and leather products	Sludges	Chrome salts, oils, dyes, organics, acids
32	Stone, clay, concrete	Sludges particulates, slag, mining and milling fibers	
33	Primary metals	Sludges, pickling liquors	Sulfur, ammonia chlorides, phenols, cyanide, oils, chrome, alkalis, acids
		Slag	Oxides, sulfur, iron
		Slimes and tailings	Copper, zinc, lead, aluminum
34	Fabricated metals	Annodizing sludges, chromating sludges, phosphating sludges, galvanizing sludges, electroplating sludges	Metallic salts, acids, oils, alkalis, evanides
35	Electrical utilities	Particulates, sludges	Fly ash, sulfur dioxide

[a] Data of Merritt and Galida (*5*).

knowledge of hydrology, geology, biology, agronomy, chemistry, and engineering. The decomposition of landfilled solid wastes generally occurs in an anaerobic environment. Drainage of water through a landfill can produce leachate containing all types of organic and inorganic dissolved compounds. These leachate constituents can pollute the receiving groundwater or surface water. A summary of representative data on initial leachate composition derived from municipal solid waste is shown in Table 4.

Large quantities of combustible methane gas, as well as inert carbon dioxide, are continuously generated by organic decomposition in sanitary landfills. Methane gas is explosive when present in air in the range of 5–15% by volume; it is odorless and does not dissolve significantly in water. The methane gas has been known to migrate several thousand feet from a sanitary landfill, and to cause severe explosions in buildings, sewers, and other structures. Analysis of typical landfill gas constituents is shown in Table 5.

Engineering classification of disposal sites based on the local geology, hydrology, topography, and the types of wastes is described in Table 6. This classification was originally developed by the State of California Water Pollution Control Board, Los Angeles Region. Class 1 landfill sites are located in nonwater-bearing locations which are not connected with groundwater and can, therefore, re-

Table 4. **Composition of initial leachate from municipal solid waste.**[a]

Component	Composition, mg/l.[b]			
	Study A		Study B	
	Low	High	Low	High
pH	6.0	6.5	3.7	8.5
Hardness, $CaCO_3$	890	7600	200	550
Alkalinity, $CaCO_3$	730	9500		
Ca	240	2330		
Mg	64	410		
Na	85	1700	127	3800
K	28	1700		
Fe (total)	6.5	220	0.12	1640
Ferrous iron	8.7[c]	8.7[c]		
Chloride	96	2350	47	2340
Sulfate	84	730	20	375
Phosphate	0.3	29	2.0	130
Organic N	2.4	465	8.0	482
NH_4N	0.22	480	2.1	177
BOD	21,700	30,300		
COD			809	50,715
Zn			0.03	129
Ni			0.15	0.81
Suspended solids			13	26,500

[a] Data of Brunner and Keller (6).
[b] Average composition, mg/l. of first 1.3 liters of leachate per cubic foot of a compacted, representative, municipal solid waste.
[c] One determination.

Table 5. Landfill gas composition.[a]

Time interval since start of cell completion, months	Content, average % by volume		
	N_2	CO_2	CH_4
0-3	5.2	88	5
3-6	3.8	76	21
6-12	0.4	65	29
12-18	1.1	52	40
18-24	0.4	53	47
24-30	0.2	52	48
30-36	1.3	46	51
36-42	0.9	50	47
42-48	0.4	51	48

[a] Data of Brunner and Keller (6).

ceive all types of solid waste, including toxic or hazardous materials. Normal municipal wastes are disposed of into so-called Class 2 sites located less than a specified minimum distance above any potential groundwater table (commonly 3 m).

Materials disposed into a Class 2 or 3 landfill site should not contain hazardous or toxic industrial wastes. Provisions are made for monitoring the subsurface groundwater for leachate pollution. In most areas of the semiarid western United States the rainfall is not sufficient enough to saturate a sanitary landfill when proper surface drainage is engineered to avoid concentration and percolation into the landfill. Diversion drains and impervious or sloped surfaces are used to prevent leachate in all types of disposal sites. Class 3 disposal sites are used solely for relatively more inert type solid wastes such as construction refuse, demolition rubble, broken concrete and asphalt, earth, and street sweepings.

In the last few years there has been concern about developing special facilities for landfilling segregated hazardous wastes in a secure area. The secure landfills should provide for separation of incompatible hazardous wastes—for example, chemicals which can cause dangerous reactions are not mixed but, rather, are separated in fenced and lined basins to prevent fires, explosions, or other hazards that may occur as a result of chemical or biochemical reactions.

Secure landfills may have double liners with monitoring wells to test that there are no leaks in the lining; in addition, they may be provided with collection sumps to store any possible under-drainage. Negative drainage created by perimeter barriers and interior collection wells can also support fail-safe leachate controls. Secure areas should be double-fenced and posted. In addition, on-site landfill facilities may have treatment works for neutralization of acid and alkali wastes. The segregation of unmixed solid waste or sludge residues also allows for their reclamation by employing the relatively pure waste residue as a raw material for new products. For example, some oily wastes may be reclaimed as fuel.

Special vehicles should be used to haul and unload hazardous wastes at secure landfills. The vehicles should carry manifests which describe the chemical analysis of the hazardous wastes carried, the quantities, the original owner, the disposal location, and, if necessary, proper handling and landfill disposal procedures. Secure landfills, as well as other classes of landfills should have provisions for perpetual site maintenance and environmental monitoring to avoid future pollution or land use problems. Perpetual site maintenance may be provided by public agencies or by suitable private trust funds.

In addition to the trend toward improved solid waste engineering, treatment, control, monitoring, and maintenance practices, there has also been increased concern with the health and safety of personnel handling municipal solid wastes. Solid waste collection and disposal has been traditionally one of the most dangerous occupations in the United States. Under the Federal Occupational Safety and Health Act there has been greater impetus to protect employees from accidents, weather, and flying debris. Uncontrolled public scavenging of solid wastes is now in disfavor because of the health and safety hazards that may be associated with solid

Table 6. Classification of disposal sites.[a]

Class	Characteristics	Wastes acceptable for disposal at class disposal site[b]
Class I	Sites located on nonwater-bearing rocks or underlain by isolated bodies of unusable groundwater, which are protected from surface runoff and where surface drainage can be restricted to the site or discharged to a suitable wasteway, and where safe limitations exist with respect to the potential radius of percolation	No limitation as to either solid or liquid wastes
Class II	Sites underlain by usable, confined, or free groundwater when the minimum elevation of the dump can be maintained above anticipated high groundwater elevation, and which are protected from surface runoff and where surface drainage can be restricted to the site or discharged to a suitable wasteway	Limited to ordinary household and commercial refuse and other rubbish, garbage, decomposable organic refuse, and scrap metal of the nature indicated below at safe elevations above anticipated high groundwater elevation in the vicinity of the site: Empty tin cans Metals Paper and paper products Cloth and clothing Wood and wood products Lawn clippings, sod, and shrubbery Hair, hide and bones Small dead animals Roofing paper and tar paper Thoroughly quenched ashes from high temperature incinerators Unquenched ashes mixed with refuse Market refuse Garbage All material acceptable at Class III without regard to elevation of anticipated high groundwater
Class III	Sites so located as to afford little or no protection to usable waters of the state	Limited to nonwater-soluble, nondecomposable inert solids of the nature indicated below Earth, rock, gravel, and concrete Asphalt paving fragments Glass Plaster and plasterboard Manufactured rubber products Steel mill slag Clay and clay products Asbestos shingles

[a] American Public Works Association classification (7).

[b] This list is not intended to be complete or comprehensive but rather an indication of the nature of wastes acceptable at each class of disposal site. Materials other than those listed may be considered separately by the interested governmental agencies and the Regional Water Pollution Control Board.

waste materials.

The U. S. Environmental Protection Agency 208 planning elements will influence future solid waste management since solid wastes include point sources, intermittent, and non-point sources of pollution. Comprehensive water quality planning requires that both physical (structural), and management (nonstructural) techniques be used to control water pollution at existing and anticipated future soil waste sites.

Nonpoint sources of solid waste include agriculture, silvaculture, abandoned and active mines, construction and run-off from completed structures, subsurface waste disposal in wells and excavations, salt water intrusion, hydrologic modification, onsite sewage land disposal, diffused sources from waste type land disposal practices and air quality changes that may result in "acid rain" or other fallout.

The first purpose of the 208 planning elements is to develop alternative pollution control methods for municipal and other solid wastes. To accomplish this task, an inventory of the extent of solid waste is first required. Secondly, a coordinated area-wide solid waste plan must be developed under an overall state program. The third activity is to estimate the future solid waste load based on projected population, use, economic activities, and required water and air pollution control requirements. The fourth step is to evaluate the control and surveillance programs for monitoring the solid waste. The fifth step is to establish priorities for the different categories of individual solid waste according to their pollution impacts, as well as their economic and social effects. The last and sixth step is to establish a solid waste pollution control schedule for all point source and non-point source solid wastes for implementing the abatement program. Permits are being required to enforce the local, State and Federal government solid waste program.

Municipal solid waste management is similar in economic magnitude to water, sewage, or power utilities. In the United States, over 6 lb (2.7 kg) per capita per day, that is, more than 2000 lb (900 kg) of municipal solid waste per capita per year, are generated. With the increased requirements for clean air and water, even more solid waste will be disposed to the land. Municipal solid wastes are now recognized as an important source of hazardous pollutants that must be properly controlled. The recent federal solid waste legislation in Public Law 94-580, entitled the Resource Conservation and Recovery Act of 1976 (*8*). A major provision under Subtitle C is concerned with hazardous waste management. Hence in the future even greater emphasis will be placed on regulating hazardous solid waste in the municipal and other source streams.

REFERENCES

1. Ralph Stone and Company, Inc. Disposal of Sewage Sludge Into a Sanitary Landfill. EPA SW-71d 1974.
2. Ralph Stone and Company, Inc. Underground incineration of solid wastes. Report, U. S. Public Health Service Grant GO6-EC-00190, July 1970.
3. Kaiser, E. Thermal processes for refuse reduction. Paper presented at APWA, Institute for Solid Wastes, Annual Meeting, Boston, Mass., Oct. 1-5, 1967.
4. Hickman, H. L., Jr. Characteristics of municipal solid wastes. Scrap Age, Feb. 1969.
5. Merritt, G. L., and Galida, G. R. Overview of residuals management in Pennsylvania. Land Application of Residual Materials. Proceedings Engineering Foundation Conference. Easton Maryland, September 26-October 1, 1976, American Society of Civil Engineers, New York.
6. Brunner, D. R., and Keller, D. J. Sanitary landfill design and operation. EPA Publication, SW-65 ts, U. S. Government Printing Office, Washington, 1972.
7. American Public Works Association. Municipal Refuse Disposal, 2d ed., Interstate Printers and Publishers, Danville, Ill., 1966.
8. Resource Conservation and Recovery Act of 1976 and Title II—Solid Waste Disposal, Public Law 94-580, 94th Congress, Oct. 21, 1976.